

- IV. "Chemical Analysis of the Meteoric Stone found at Makariwa, near Invercargill, New Zealand, in the year 1886."
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(Abstract.)

As the preliminary investigation of the Makariwa stone had already indicated to Professor Ulrich* the presence of mineral constituents having the physical characters of olivine, enstatite, glass, a substance resembling glass, nickel-iron, troilite, magnetite, hydrous oxide of iron, and possibly chromite, the quantitative chemical analysis presented difficulties, among which may be specially mentioned the fact that one chemical element (iron) enters into the composition of each of the above fine-grained and closely intermingled constituents. This chemical examination I was invited to undertake by Professor J. W. Judd, F.R.S., through whom the two fragments of the stone sent to this country by Professor Ulrich have been generously presented to the British Museum.

The composite method adopted for the analysis was as follows :—

It was found advisable to make a preliminary separation of the powder by means of a magnet into attracted and unattracted material. Treatment of a portion of the attracted material with a solution of mercuric ammonium chloride, as recommended by Dr. Friedheim,† revealed the fact that the proportion of rust was too large to be negligible, and indicated the necessity of a preliminary reduction of the rust of the unattracted material, and of a subsequent extraction of the reduced metal with mercuric solution; this prevents the unattracted oxide of iron due to rusting of the alloy from passing into the hydrochloric acid extract with the oxide of iron of the silicate decomposed by the acid. Accordingly, after the sulphur and phosphorus of the unattracted material had been determined, mercuric solution was employed both before and after heating the material to low redness in a current of hydrogen (as recommended by von Baumhauer), the residual unrusted and rusted nickel-iron being thus separately removed. Analysis of the post-reduction mercuric extract showed that there had been a small, but appreciable, action on the silicate portion of the meteorite during the reduction. Further, it became obvious that the troilite was largely affected by the heating in hydrogen, and in such a way that the greater part of the iron of that constituent, and practically all the iron and nickel of the schreibersite, had gone into the mercuric

* 'Roy. Soc. Proc.,' 1893, vol. 53, p. 54.

† 'Sitz. Ak. Berlin,' 1888, p. 345.

solution. Hence, determinations of the sulphur and phosphorus in the mercurialised residue were made, so that the iron and nickel which had passed into the mercuric solution from the affected troilite and schreibersite might be allowed for. The mercurialised residue was next treated with hydrochloric acid, and the solution analysed; the silica was extracted from the undecomposed residue by sodium carbonate solution containing some caustic soda, and the small amounts of bases simultaneously extracted were likewise determined; the undecomposed residue itself was then separately analysed. Further, various determinations of the alkalis were made.

The microscopical examination made by Professor Ulrich having suggested no character or constituent different from those previously met with in meteoric stones, the interest of the chemical investigation was rather in the study of an analytical method than in the numerical results to be obtained. As pointed out by Dr. Friedheim, in the memoir already referred to, recent analyses of fragments of the Alfanello stone show enormous variations: they are probably in great part due to the incompleteness of the separations of the constituent minerals from each other.

As a result of the observations made in the course of the analysis of the Makariwa stone, the following points may be emphasised:—

1. It is advisable to first effect, as far as practicable, a magnetic separation of the mineral constituents: otherwise, owing to the malleability of the nickel-iron, the powdered material may be neither sufficiently fine, nor sufficiently homogeneous as a mixture. Further, without this separation, the appreciable proportion of the iron-rust may escape observation.

2. The solution of mercuric ammonium chloride, suggested by Dr. Friedheim, is very satisfactory in being without appreciable action on any other constituent than the nickel-iron, if used as directed.

3. If the attracted material be treated with acid without previous extraction by means of mercuric solution, the composition deduced for the nickel-iron may be completely wrong, owing to the solution of iron-rust simultaneously with the nickel-iron.

4. After reduction of the rust in the unattracted material by heating to low redness in hydrogen, and after subsequent treatment with the mercuric solution, no troilite or schreibersite will be left in the residue if the operations are sufficiently prolonged. There is an appreciable effect on the silicate portion during the operations.

5. The enstatite can be completely freed from olivine by three extractions with hydrochloric acid (sp. gr. 1.06) on the water-bath—probably by two.

6. The Deville-Cooke method is very advantageous for the separation of the small quantities of aluminium and chromium from the iron.

It may be added that the microscopical characters of minerals have now been so minutely investigated that, for mere determination of the mineralogical species of the constituents, the microscopic examination of a thin section of a meteorite by the petrologist is more complete and expeditious than a chemical analysis.

The following numerical results were deduced from the observations, an account of the technical details of which will appear in the 'Mineralogical Magazine':—

I. *Mineralogical Composition of the Stone.*

(a.) *After weathering—*

Metallic iron	1.55
Metallic nickel (cobalt)	1.08
Copper	trace
Oxide of iron (Fe_3O_4)	3.48
Olivine (including glass and substance resembling glass)	48.61
Enstatite	38.40
Troilite	5.94
Schreibersite	0.63
Chromite	0.31
	100.00

(b.) *Before weathering—*

Nickel-iron	5.20
Olivine	49.08
Enstatite	38.77
Troilite	6.00
Schreibersite	0.64
Chromite	0.31
	100.00

(c) *Ratios of constituents—*

100 parts of the silicate portion would consist of 55.87 parts of olivine and 44.13 parts of enstatite.

100 parts of the original nickel-iron would consist of 78.94 of iron and 21.06 of nickel (cobalt); the analysis of 0.1450 gram of the residual nickel-iron gave 82 per cent. of iron and 18 per cent. of nickel (cobalt).

The nickel and cobalt are in the proportion to each other of 4.7 : 1, or of 12 : 1; the former proportion was deduced from the analysis of reduced rust, the latter from analysis of the mercuric extract of the residual unruined alloy itself, which may have a different composition.

II. *Percentage Composition of the Enstatite.*

SiO ₂	54.46	Oxygen.
MgO	22.76	28.87
FeO	16.74	} 14.51
CaO	4.17	
MnO	0.39	
Al ₂ O ₃	0.21	
K ₂ O	0.15	
Na ₂ O	1.12	
Li ₂ O	trace	
100.00		

This corresponds very closely with the typical enstatitic formula $R''O \cdot SiO_2$, and shows that all the olivine had been extracted.

III. *Percentage Composition of the Olivine (including Glass and Substance resembling Glass).*

SiO ₂	40.68	Oxygen.
MgO	35.64	21.56
FeO	22.06	} 19.62
CaO	1.16	
MnO	0.29	
Al ₂ O ₃	0.17	
100.00		

This corresponds approximately with the typical formula of an olivine, $2R''O \cdot SiO_2$. The deviation from the typical formula is probably chiefly due to solution of part of the finely-divided enstatite during the separation of the olivine by means of hydrochloric acid, and may partly arise from the solution of the other constituents mentioned by Professor Ulrich, "glass and a substance resembling glass."

IV. *Alkalies.*

The various determinations made of the alkalies were consistent in indicating that the alkali present is essentially soda, and that the soda is almost wholly, if not solely, present in a mineral constituent which is only slightly attacked by water, alcohol, ether, or dilute hydrochloric acid.

V. *Chemical Relationship to other Meteoric Stones.*

For the olivinic silicate, the ratio of the oxygen in combination with the iron and manganese to that in combination with the magnesium and calcium is 1 : 2·9; in this respect the Makariwa stone resembles those of Gopalpur (1 : 2·75); Mezö-Madaras and Eichstädt (1 : 2·8); Montréjeau and Pultusk (1 : 2·9); Borkut and Chantonmay (1 : 3).*

For the enstatitic silicate, the corresponding ratio is 1 : 2·7. This approximates to those of Eichstädt (1 : 2·2); Manegaum, Waconda, and Tjabé (1 : 2·3); Seres (1 : 2·4); Georgia and Montréjeau (1 : 2·5); Grosnaja (1 : 2·6); Utrecht (1 : 2·7); Ski (1 : 2·8); Borkut (1 : 3).

Of the above meteoric stones, that which stands nearest in this respect for both silicates is Montréjeau; other stones approximating to Makariwa in both ratios are Borkut, Eichstädt, Tjabé, Utrecht, and Linn County.

In the proportion of the olivine to the enstatite, there is also a close similarity: in Makariwa the proportion is 56 : 44; in Montréjeau, 54 : 46.

The proportion of nickel (18—21 per cent.) in the alloy is higher than the average, and approximates to that of Middlesbrough (23 per cent.).

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* 'Die Chemische Natur der Meteoriten,' von C. F. Rammelsberg. Berlin, 1879.